Identification of Cost Effectiveness Measures Using Response-Surface Modeling

Prepared for OPEI conference on Cost-Effectiveness Analysis for Multiple Benefits

Motivation

- Cost-effectiveness metrics
  - $/ton metrics ignore ignore differences in contribution to ambient PM between sources and locations of precursor emissions.
  - $/microgram metrics may be more appropriate, but deriving these metrics using complex air quality models can be time consuming and expensive
- The relationship between ambient concentrations in any particular receptor location and emissions at a source location may be affected by numerous factors:
  - distance and emission release height,
  - meteorology, and
  - base conditions at the receptor
- Response-surface modeling (RSM) seeks to represent the relationship between model outputs and input parameters in a parsimonious fashion, using relatively simple polynomial representations to approximate model functions.

RSM Pilot Study

- Baseline Emissions Data
  - Source region = Southeast
  - Two broad source groupings = elevated and low level sources
  - PM2.5 precursor emissions = NOX, SO2, NH3, VOC, primary organic particles
- REMSAD air quality model
  - Domain = Continental US w/ 36km grids (~5,000 grids)
  - Model runs = 4 months representing each season
- Experimental design
  - Covers from zero to 120 percent of baseline emissions
  - Requires 144 total runs to characterize a second order polynomial surface
- Develop statistical model of response surface

Response Surface Specifications I:
Continental Response Surface

- Includes every grid cell in the continental U.S.
- Controls for receptor attributes including
  - Distance from source emissions
  - Baseline emissions at receptor, and
  - Meteorology.
- Accounts for spatial autocorrelation and gridcell level effects using a random effects version of a spatial autoregression model
- Allows you, for example, to predict the mean change in PM2.5 in an urban receptor with high ammonia levels, given a reduction in SO2 emissions in the Southeast.

Response Surface Specifications I:
Non-attainment Area Surfaces

- Focus on grid cells covering counties expected to be in non-attainment of the 15 ug/m3 annual standard for PM2.5
- Separate response surface can be estimated for each non-attainment area
- Combined response surface can be fit across non-attainment areas by using a random-effects model controlling for area specific effects as well as previously mentioned receptor attributes

Additional Response Surfaces

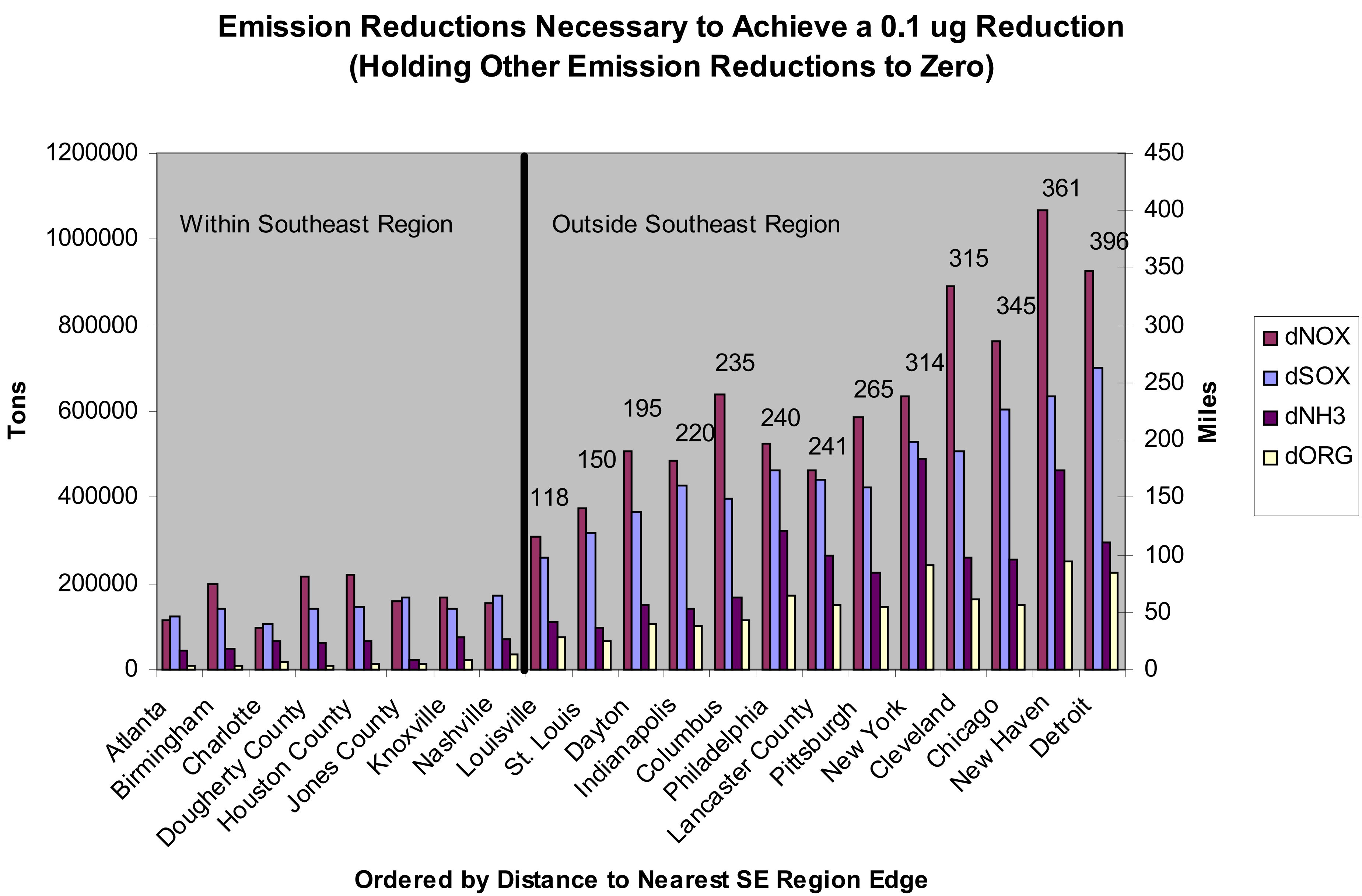
- Seasonal models
  - Focus on individual changes in seasonal mean PM2.5 rather than annual mean
- PM constituent models
  - Focus on changes in individual constituent species, e.g. sulfates or nitrates, rather than on changes in total PM2.5 mass

Preliminary Modeling Results of Non-attainment Area Surface for Elevated Sources

- Individual city-level analyses revealed stable, parsimonious specification:

$$\Delta PM2.5 = \beta_1 \Delta NOx + \beta_2 \Delta SO_2 + \beta_3 \Delta VOC + \beta_4 \Delta NH_3 + \beta_5 \Delta OP$$
$$+ \beta_{11} \Delta NOx^2 + \beta_{22} \Delta SO_2{}^2 + \beta_{12} \Delta NOx \Delta SO_2 + \beta_{14} \Delta NOx \Delta NH_3$$

- Adjusted R-square values were around 0.98 – 0.99 across non-attainment areas
  - Thus, RSM able to reproduce REMSAD model responses to changes in precursor emissions very well



Emission Reductions Necessary to Achieve a 0.1 ug Reduction
(Holding Other Emission Reductions to Zero)
Within Southeast Region
Outside Southeast Region
Tons
Miles
0
200000
400000
600000
800000
1000000
1200000
0
50
100
150
200
250
300
350
400
450
118
150
195
220
235
240
241
265
314
315
345
361
396
Atlanta
Birmingham
Charlotte
Dougherty County
Houston County
Jones County
Knoxville
Nashville
Louisville
St. Louis
Dayton
Indianapolis
Columbus
Philadelphia
Lancaster County
Pittsburgh
New York
Cleveland
Chicago
New Haven
Detroit
dNOX
dSOX
dNH3
dORG
Ordered by Distance to Nearest SE Region Edge

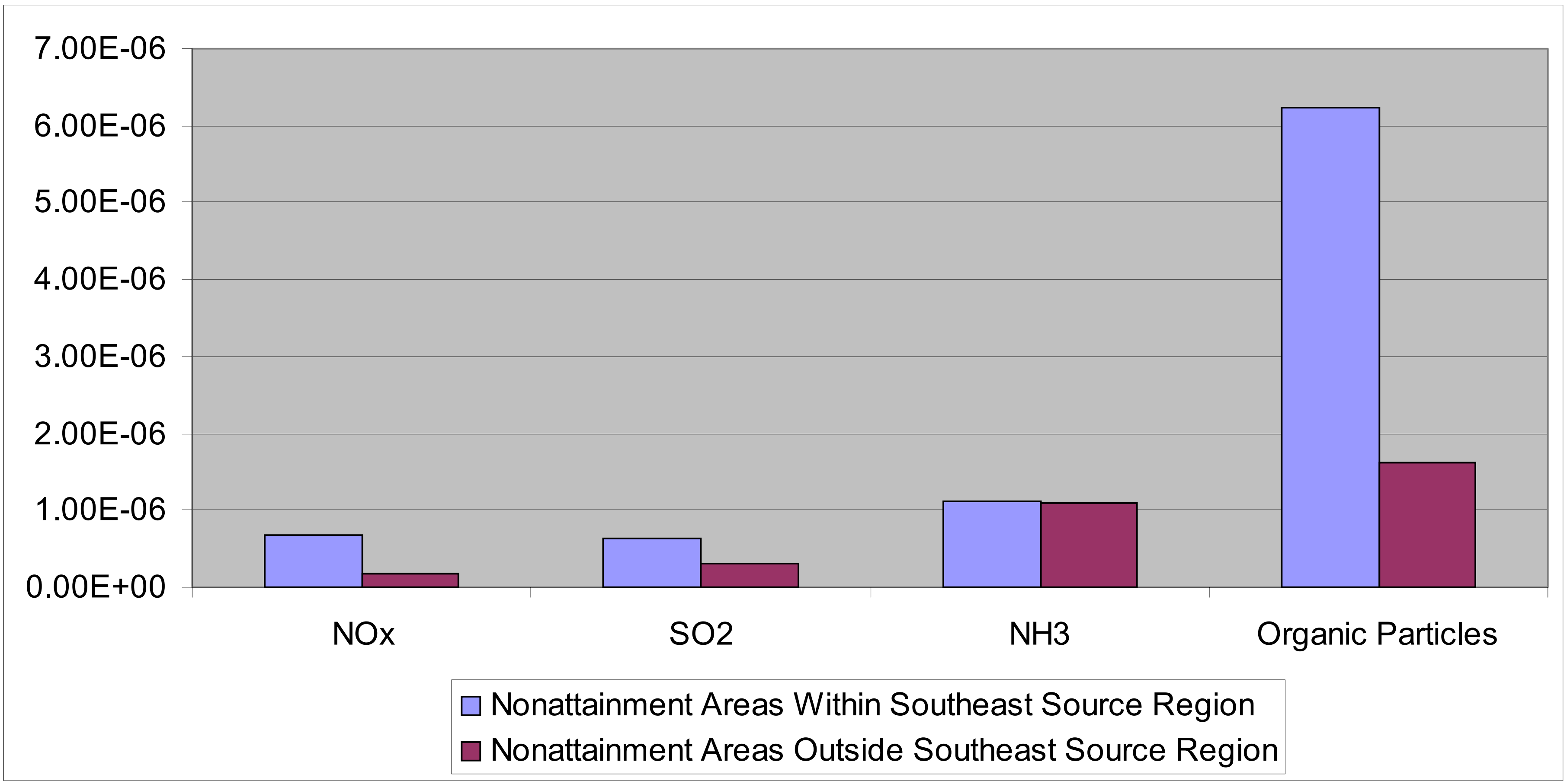
Cost-effectiveness: $/μg

- RSM provides μg/ton estimates
- Can be combined with $/ton estimates to get $/μg estimates, i.e.,

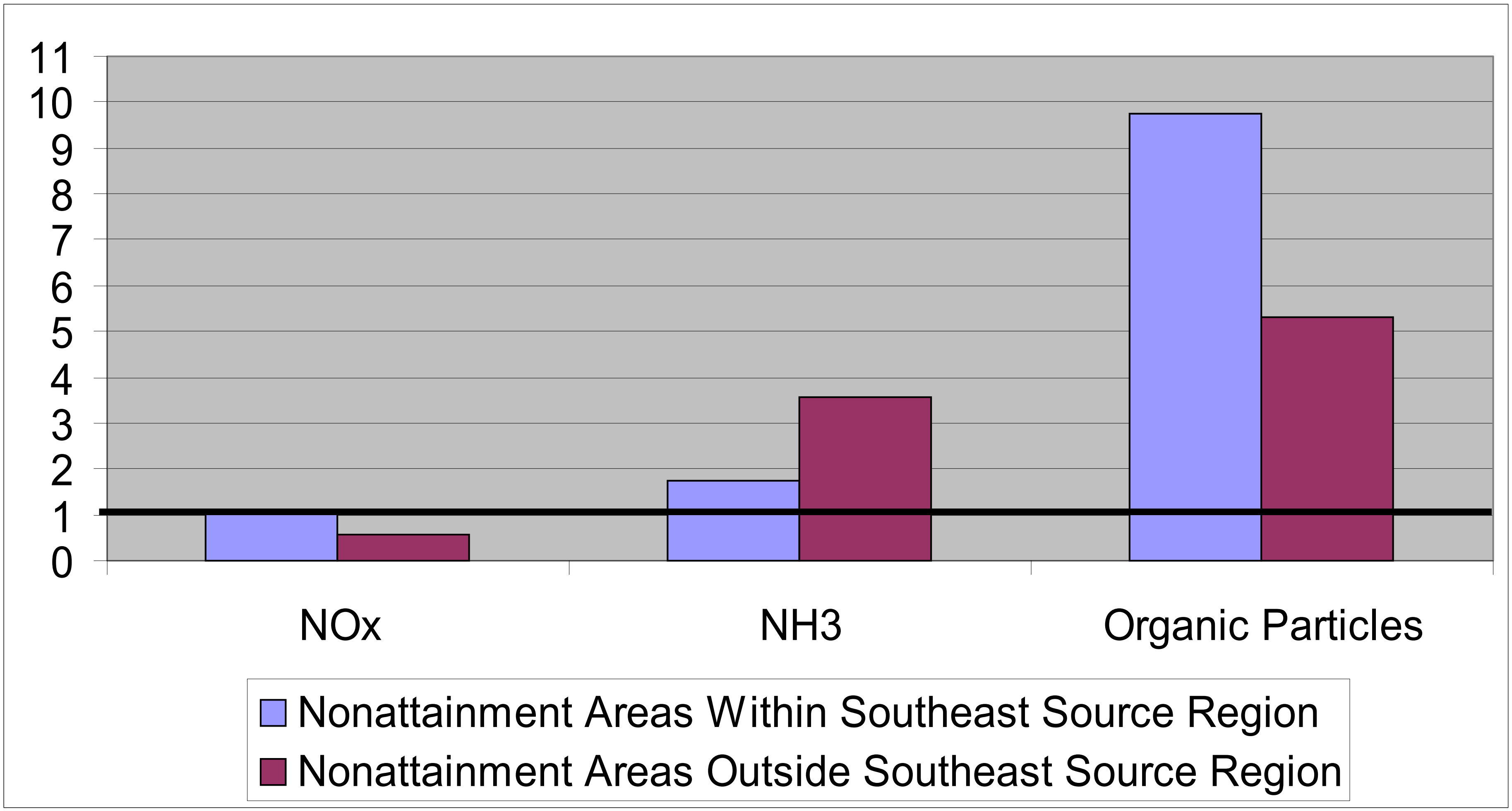
$$\$/\mu g = (\$/ton)/(\mu g/ton)$$

- Rankings of control strategies may differ based on type of effectiveness metric selected

RSM pilot reveals the following preliminary µg/ton estimates:



Ratio of Impacts Relative to SO2



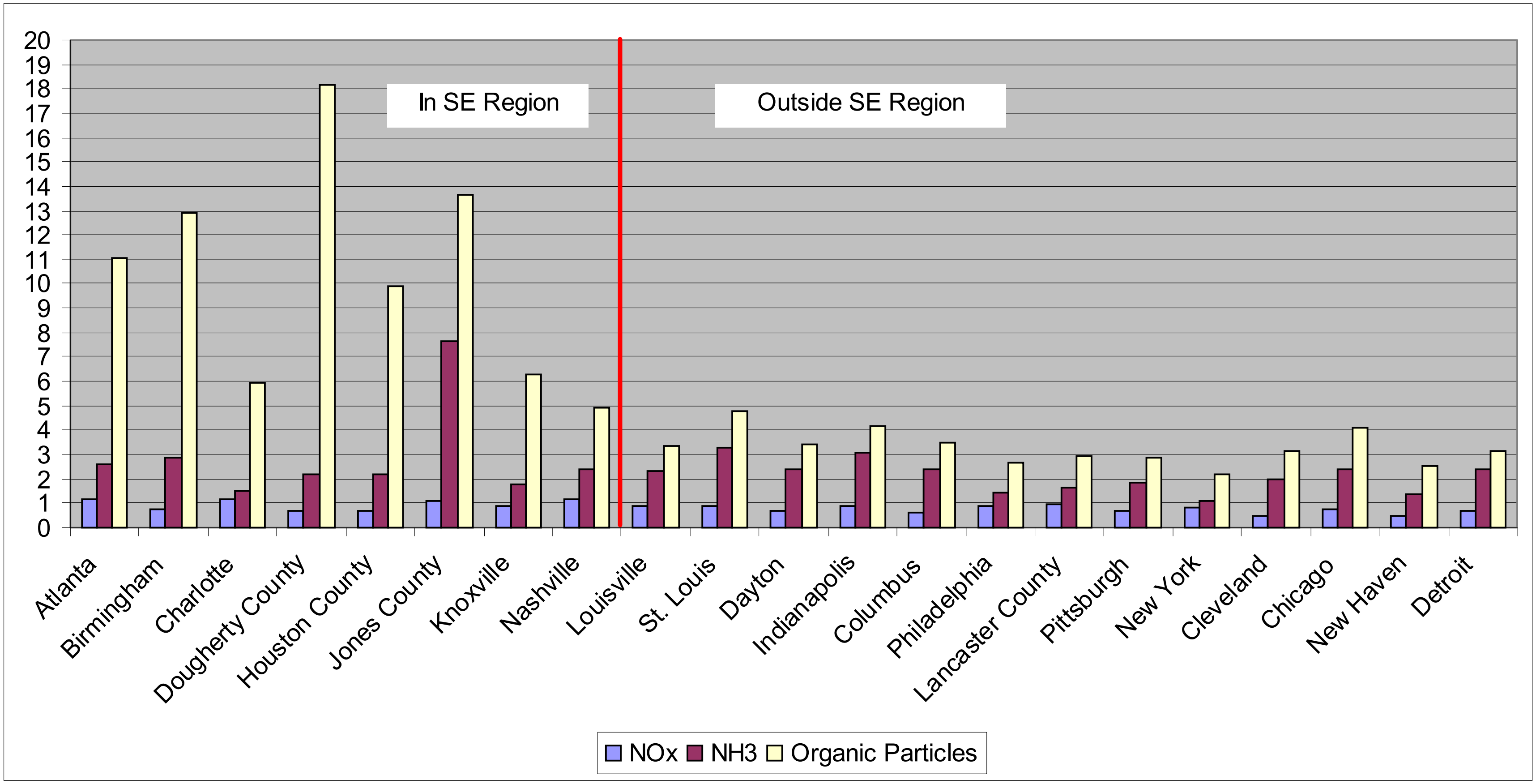
Implications

- RSM ratios imply that $/ton for SE region NOx reductions has to be about half that for SO2 to be as cost-effective (in $/ : g terms) as SO2 reduction for NA areas outside the SE region.
- So for current estimates of around $1,000 per ton reduced of SO2, you would need to get NOx reductions at a cost of $500 per ton or less to be cost-effective.
- Also implies that in the SE, ammonia controls at less than $3,500 per ton and organic particle controls at less than $5,300 per ton will be cost-effective relative to SO2 in achieving ambient reductions in non-attainment areas outside of the SE.
- Note that these are just illustrations using the preliminary RSM pilot study results.

More implications

- Pilot results suggest that impacts on NA areas within a region can be substantially greater than out of region, and that the optimal mix of reductions may be different
- In our example, within-region NOx reductions will be more effective relative to SO2 reductions, so that the $/ton required for cost-effective NOx reductions relative to SO2 is around $1,100/ton.
- The difference is even more pronounced for organic particles where control measures costing up to $9,700 per ton will be more cost-effective than SO2 in achieving ambient PM2.5 reductions.

However, there is variability in relative µg/ton impacts across non-attainment areas…



Cost-effectiveness then depends not only on which pollutant, but on which non-attainment area is targeted.

Next Steps

- Conduct additional model runs for SE region to better characterize response surface.
- Extend to other source regions through additional model runs and estimation of response-surfaces
- Use RSM for optimization applications, i.e.,
  – Nonlinear programming or other optimization methods can be used to solve for optimal combination of NOx, SO2, NH3, and organic particle reductions to achieve targeted μg/m3 reduction in multiple non-attainment areas